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How ubiquitous are massive starbursts in interacting galaxies?

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Abstract. Many evidences exist for a connection between galaxy interactions and induced star formation. However, a large range of responses of galaxies to tidal interactions is found, both in observations and in numerical simulations. We will discuss some recent results obtained analysing a large sample (~ 1000) of simulations of interacting pairs and their agreement with the most recent observational works.

1. Introduction

1.1. Interactions and star formation: observations

In the local Universe, the response of galaxies to mutual interactions is quite varied. The strongest starbursts are found in interacting and merging systems (Joseph & Wright 1985; Sanders et al. 1988; Clements et al. 1996; Sanders & Mirabel 1996; Scoville et al. 2000; Arribas et al. 2004; Alonso-Herrero et al. 2006) and many studies have shown that interacting pairs show an increased star formation, lasting few $10^7 - 10^8$ years (see Kennicutt et al. 1996 for a review), which can take place in the galaxy centers, as it is the case of M82 (de Grijs et al. 2001), or in the overlapping regions between galaxies, as for the Antennae (Wang et al. 2004). Nevertheless, interactions and mergers do not seem a sufficient condition to trigger high star formation episodes. Bergvall et al. (2004) have shown only a weak enhancement in the star formation rate (hereafter SFR) of a sample of interacting pairs (by a factor of 2-3 in their centers), when comparing their optical colors to those of a sample of non-interacting systems. More recently, Knapen & James (2009) have shown that the SFR of galaxies with close companions is enhanced by a factor of around two when compared to galaxies without companions and that the increase in the SFR does not occur in a burst mode of massive star formation, but it is rather continuous, with a duration of the order $10^8 - 10^9$ years.

At higher redshifts, merger-induced star formation is debated too. Conselice et al.

(2003) suggested that about two thirds of submillimeter galaxies at $z > 1$ are undergoing a major merger; also Bridge et al. (2007) argued for a significant role of mergers in the SFR density at $z \sim 1$. However, Bell et al. (2005) found that less than one third of actively star forming galaxies at $z \sim 0.8$ are interacting systems. Similar results have been found by Jogee et al. (2009), who showed that merging systems only account for a small fraction ($< 30\%$) of the cosmic SFR between $0.24 \leq z \leq 0.8$, and that at these redshifts the mean SFR of merging systems is only modestly enhanced compared to non-interacting galaxies. These results have been further confirmed by Robaina et al. (2009), who argue that less than 10% of star formation in massive ($M_* > 10^{10} M_\odot$) galaxies is triggered by mergers, thus deducing that these events do not strongly contribute to the build-up of the stellar mass since $z=1$.

1.2. Interactions and star formation: numerical simulations

Since the work by Barnes & Hernquist (1991), it has been shown that tidal interactions can drive large quantities of gas into the galaxy central regions, with a subsequent increase in the SFR of the system. Negative gravity torques acting on the gas component inside the disk corotation radius reduce its angular momentum and can cause an important inflow in the nuclear regions, where a starburst can occur (Mihos & Hernquist 1994, 1996; Springel 2000; Cox et al. 2006, 2008). The timing and the strength of the induced starburst depend on a number of parameters, in particular on the morphology of the interacting galaxies, bulgeless disk galaxies being more prone to bar instability in the first phases of the interaction, when a strong burst of star formation can occur, while bulge-disk galaxies usually show the peak of their star formation activity in the final merging phases (Mihos & Hernquist 1994). Equal-mass mergers are the most efficient mechanisms to trigger strong starbursts, and the star formation activity declines rapidly with increasing mass ratios (Cox et al. 2008). In particular, for unequal mass mergers, while the most massive galaxy contributes to the majority of the star formation of the system, the less massive satellite usually experiences the largest enhancement in its star formation, which is hidden in the total rate of the pair (see Fig.8, Cox et al. 2008).

That galaxy interactions can lead to strong bursts of star formation, as shown in Mihos & Hernquist (1994), does not necessarily implies that they are a sufficient condition to systematically produce high star formation enhancements. For example, Kapferer et al. (2005) showed, by analysing a sample of ~ 50 simulations of galaxy interactions, that the integrated SFR during an interaction is moderately increased, up to a factor of 5 but on average a factor of 2 with respect to that of isolated galaxies. Modelling the interacting pair NGC4676 (the Mice), Barnes (2004) showed that, independently on the numerical recipe adopted for star formation (density or shock dependent), the maximum star formation enhancement found during the interaction is a factor of ten at most with respect to pre-interaction levels. More recently, Di Matteo et al. (2007) analysed a sample of more than two hundred realisations of galaxy collisions, pointing out the difficulty to obtain strong merger-driven starbursts, and discussing the dependence of the final SFR on a number of encounter parameters (relative distance at first pericenter passage, relative velocity, strength of tidal effects, etc...).

In what follows, we will discuss the main results recently obtained (Di Matteo et al.

2008) by analysing two independent numerical samples of major galaxy mergers, realised employing different numerical techniques to model baryonic and dark matter evolution, and to implement star formation.

2. Results from two independent large numerical samples of major galaxy mergers

In Di Matteo et al. (2008) we have extended the work presented in Di Matteo et al. (2007), by realising and analysing a sample of ~ 890 simulations of interacting and merging galaxies (864 for local interactions and 24 for high-redshift systems). These simulations cover a large range in morphologies (from bulgeless to early-type galaxies), orbital parameters and gas fraction (from 10% to 50%). They have been run adopting a Tree-SPH code (Semelin & Combes 2002), with a density-dependent star formation prescription, feedback from SNe explosions and metal enrichment. These simulations have been realised in the framework of the GalMer project and are available at <http://galmer.obspm.fr> (see also Chilingarian et al. 2009).

To study whether our conclusions depend on the numerical techniques and star formation schemes adopted, we have run a second set of 96 simulations with a different numerical code, a particle-mesh code with a sticky-particle (PM-SP) modeling of the ISM (see Bournaud & Combes 2003), employing also star formation models that differ from the density-dependent Schmidt law.

2.1. Intensity of starbursts episodes

These simulations confirm our previous results (Di Matteo et al. 2007) about the variety of star formation evolutions and enhancements that can be found in interacting pairs.

In agreement with observations, it results that *mergers do not always trigger starbursts*, and this result appears to be robust because it is found in both numerical codes used (Tree-SPH and PM-SP) and does not change significantly when using star formation prescriptions different from a pure Schmidt law. For galaxies with gas content typical of local or low-redshift galaxies, the starbursts induced by galaxy major mergers have a moderate intensity, SFRs being rarely enhanced by factors larger than 5 compared to isolated galaxies, even at the peak of the starbursts. About 10% of pairs in our sample shows a star formation enhancement at least ten times higher than the SFR of an isolated reference sample. Independently of the code used and star formation recipe adopted, we find a median value for the maximal relative SFR of about 3.

2.2. Duration of starbursts episodes

In our models, the duration of the moderate starbursts is generally smaller than 500 Myr, and no more than 15% of interaction-induced starbursts have a duration greater than 500 Myr.

2.3. From the local Universe to higher redshifts

When disks have higher gas fractions (about 50%), interacting pairs show higher star formation rates than low-redshift systems. When normalized to the SFR

of the corresponding galaxies evolved isolated, inflow-induced starbursts do not result to be stronger than their local counterparts. Also the duration of the inflow-driven star formation enhancement is not longer than that of local systems. We note, however, that the formation of massive clumps in our gas-rich disks and their induced star formation can produce longer star formation enhancements than those found for local galaxies.

Strong starbursts can occur during some major mergers, as observed, but our work suggests that merger-driven gas inflow is not always an efficient process to produce strong star formation enhancements. This result seems to be consistent with a number of recent observational works (Bell et al. 2005; Jogee et al. 2009; Robaina et al. 2009) which suggest the limited role of mergers in building up the stellar mass since $z=1$.

References

- Alonso-Herrero, A., Rieke, G. H., Rieke, M. J., et al. 2006, *ApJ*, 650, 835
 Arribas, S., Bushouse, H., Lucas, R. A. 2004, *AJ*, 127, 2522
 Barnes, J. E. & Hernquist, L. E. 1991, *ApJ*, 370, L65
 Barnes, J. 2004, *MNRAS*, 350, 798
 Bell, E. F., Papovich, C., Wolf, C., et al. 2005, *ApJ*, 625, 23
 Bergvall, N., Laurikainen, E., Aalto, S. 2003, *A&A*, 405, 31
 Bournaud, F., & Combes, F. 2003, *A&A*, 401, 817
 Bridge, C. R., Appleton, P. N., Conselice, C. J., et al. 2007, *ApJ*, 659, 931
 Chilingarian, I., Di Matteo, P., Combes, F., Melchior, A.-L., & Semelin, B. 2009, *A&A* submitted
 Clements, D. L., Sutherland, W. J., McMahon, R. G., et al. 1996, *MNRAS*, 279, 477
 Conselice, C. J., Chapman, S. C., Windhorst, R. A. 2003, *ApJ*, 596, L5
 Cox, T. J., Jonsson, P., Primack, J., et al. 2006, *MNRAS*, 373, 1013
 Cox, T. J., Jonsson, P., Somerville, R. S., et al. 2008, *MNRAS*, 384, 386
 de Grijs, R., O’Connell, R. W., Gallagher, J. S. 2001, *AJ*, 121, 768
 Di Matteo, P., Combes, F., Melchior, A.-L., & Semelin, B. 2007, *A&A*, 468, 61
 Di Matteo, P., Bournaud, F., Martig, M., Combes, F., Melchior, A.-L., & Semelin, B. 2008, *A&A* 492, 31
 Jogee, S., Miller, S. H., Penner, K. et al. 2009, *ApJ*, 697, 1971
 Joseph, R. D. & Wright, G. S. 1985, *MNRAS*, 214, 87
 Kapferer, W., Knapp, A., Schindler, S., et al. 2005, *A&A*, 438, 87
 Kennicutt, R. C., Calzetti, D., Walter, F., et al. 2005, *AAS*, 207, 6314
 Knapen, J. H. & James, P. A. 2009, *ApJ*, 698, 1437
 Mihos, J. C. & Hernquist, L. 1994, *ApJ*, 431, L9
 Mihos, C., & Hernquist, L. 1996, *ApJ*, 464, 641
 Robaina, A. R., Bell, E. F., Skelton, R. E. et al. 2009, *ApJ* submitted; *astro-ph/0907.3728*
 Sanders, D. B., Soifer, B. T., Elias, J. H., et al. 1988, *ApJ*, 325, 74
 Sanders, D. B., & Mirabel, I. F. 1996, *ARA&A*, 34, 749
 Scoville, N. Z., Evans, A. S., Thompson, R., et al. 2000, *AJ*, 119, 991
 Semelin, B., & Combes, F. 2002, *A&A*, 388, 826
 Springel, V. 2000, *MNRAS*, 312, 859
 Wang, Z., Fazio, G. G., Ashby, M. L. N., et al. 2004, *ApJS*, 154, 193